PATENT SPECIFICATION

DRAWINGS ATTACHED

COMPLETE SPECIFICATION

Friction Welding

We, AMERICAN MACHINE & FOUNDRY COMPANY, a corporation organized and existing under the laws of the State of New Jersey, United States of America, of 261
5 Madison Avenue, New York, State of New York, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be
10 particularly described in and by the following statement:—

This invention relates to apparatus for welding workpieces utilizing heat generated by friction as the pieces to be welded are
15 pressed together and relatively rotated.

The invention is applicable for the joining of metals of all kinds, such as refractory metals, steel, various alloys, cast iron, brass, titanium, aluminum and combinations there-
20 of, and including the welding of dissimilar metals, such as aluminum to steel or brass to steel, for example. It is necessary that one of the workpieces should be symmetrical or have an axis of revolution such as studs to
25 plates, bars, tubular sections, and the like and including as well, plastics.

According to the invention we provide a friction welding machine comprising a pair of gripping means for gripping workpieces, a
30 rotary device for effecting relative rotation of the gripping means, pressure means for urging the gripping means relatively towards each other so as to press the workpieces together, a flywheel, a power driven means, a first
35 clutch disengageably coupling the power driven means to the flywheel, a second clutch disengageably coupling the flywheel to the rotary device, the arrangement being such that with the second clutch disengaged suffi-
40 cient kinetic energy can be introduced through the first clutch into said flywheel to effect the weld whereupon the second clutch can be engaged and the pressure means operated to press the workpieces together to effect the

weld, the second clutch can be then disen- 45
gaged and the flywheel again driven up to required speed through the first clutch for another weld, no braking means being pro-
vided for slowing the rotary movement of the flywheel. 50

The invention is illustrated by way of example in the accompanying drawings, in which:—

Figure 1 is a side elevation of a friction welding apparatus in accordance with the 55
invention;

Figure 2 is a top plan view of the apparatus;

Figure 3 is an apparatus of modified arrangement in which the energy stored by 60
the flywheel, which comprises a plurality of engageable sections, may be varied by varying the mass of the flywheel to attune the kinetic energy stored to that required for effecting the weld of workpieces of various sizes or 65
compositions.

Figure 4 is still a further modification of an apparatus in accordance with the invention in which the flywheel arrangement is dis-
placed from the main shaft upon which the 70
workpieces are mounted.

Figure 5 is a diagrammatic illustration of the end portion of a workpiece and an ele-
mentary area on the friction plane of a surface to be considered in conjunction with formulae 75
set forth hereinafter for the purpose of more fully describing the attributes of the inven-
tion.

Figure 6 is a graph illustrating effective coefficient of friction as a function of rota- 80
tional speed and pressure.

The principle underlying the use of the present invention is that, in the joining of metallic elements, the ultimate temperature necessary for intermolecular penetration of 85
one element with that of another to effect a homogeneous integral structure is produced by friction. The material referred to in the

[*Price 4s. 6d.*]

specification is metal but it is apparent that all thermoplastic materials may be welded by this apparatus.

The use of the apparatus according to the invention involves a method for causing the homogeneous union of separate metallic elements to form an integral structure, according to which the temperature of the metals at the surfaces is raised by frictionally developed heat to a point at which fusion and intermolecular penetration occurs, so that the metallic elements on cooling are bonded homogeneously and integrally one with the other.

Referring in detail to Figures 1 and 2, an apparatus according to the invention in which welding energy is stored in a flywheel is illustrated. On the support 10 is suitably arranged a motor 11 connected through motor pulley 12 and timing or V-belt 13 to a torque tube pulley 14 to drive to a hollow torque tube 21. A clutch 15 is conventionally adapted so as to engage and disengage the drive from the motor 11 to the torque tube 21. It will be understood that a conventional centrifugal clutch (not shown) may be employed in conjunction with the flywheel to disengage the motor when the flywheel reaches the desired speed. This installation permits charging the flywheel to any desired speed providable by the motor regardless of the running speed of the drive motor. Suitably supported on the torque tube 21 in fixed relationship therewith is the flywheel 17 positioned between bearing pillow block supports 16. A second clutch 18 is employed to engage and disengage a rotary device in the form of a spindle 20 and workpiece carrying rotary chuck 22 with and from the flywheel supporting torque tube 21. A rotary chuck 22 secured to spindle 20 is employed to hold the first 27a of two workpieces to be joined to a second workpiece 27b held in the non-rotatable chuck 23. The flywheel is coaxial with the chucks and clutches. So as to hold the workpieces in proper pressure relationship to each other to effect the welding a suitable pressure apparatus of conventional design such as pressure cylinders 19, either of hydraulic or pneumatic type are utilized. Upon actuation, the cylinders 19 acting through the piston rods 25 which are appropriately secured at 29 to a back-up plate and chuck support 24 for the non-rotatable but axially slidable chuck 23 force the workpieces 27a and 27b together under suitable welding pressure. To permit movement of the chuck support 24 suitable machine ways 26 are provided.

The operation of the apparatus above described is as follows: Workpieces 27a and 27b are fixed in the rotating and non-rotating chucks 22 and 23, respectively. The motor 11 is started and the clutch 15 is engaged to rotate the flywheel (or optionally the motor is started with the clutch 15 engaged) with the clutch 18 disengaged until sufficient energy is stored in the flywheel to weld the workpieces. The clutch 15 is disengaged and the clutch 18 which drives the rotating chuck 22 holding piece 27a is engaged. At the same time, the rods 25 are actuated by the pressure cylinders 19 to draw the workpieces together. As the energy stored in the rotating mass of the flywheel is consumed, the surfaces of the workpieces are heated through friction to a plastic or molten condition at the welding interface. The coefficient of friction increases as the mass slows so that stoppage of the flywheel coincides or substantially coincides with the completion of the weld. When the flywheel has stopped, the clutch 18 is disengaged and clutch 15 connecting the motor 11 to the flywheel is engaged permitting the build-up or storage of energy in the flywheel 17 while the new welded workpiece 27 is removed and another pair of workpieces to be welded are secured in the rotating and non-rotating chucks 22 and 23, respectively. The welding cycle as described hereinabove is then repeated with a minimal of lost time. It is thus seen that the apparatus of the invention affords a novel and substantially simplified arrangement for the friction welding of workpieces.

Referring now to the arrangement of Fig. 3, an apparatus similar to that described in Figs. 1 and 2 is illustrated with the exception that a variable inertia flywheel, i.e. a flywheel with a plurality of segments, is employed in place of a single segment wheel. The arrangement comprises a combination of elements including a motor 31 which drives torque tube 36 through the conventional arrangement of motor pulley 32 timing or V-belt 33, torque tube pulley 34 and clutch 35. Supported in selectively fixed relationship on the torque tube 36 which tube is in turn supported by bearing supports 44, is the variable inertia flywheel 37 comprising a plurality of segments 37a. One or more of the flywheel segments 37a is selectively fixed to the torque tube depending on the quantum of rotating mass desired for the workpieces to be welded. Any suitable arrangement may be employed to couple and disengage one or more of the segments 37a together or to the torque tube 36. Clutch 38 functions similarly to clutch 18 shown in Fig. 2 to engage the spindle 39 rotating chuck 40 which holds workpiece 46a. The arrangement of pressure cylinders 41 and rods 42 secured to the back-up plate and non-rotating chuck support 43 function in a like manner as the corresponding elements similarly illustrated in Fig. 2.

In operation, the arrangement of Fig. 3 follows that generally described for the embodiment of Figs. 1 and 2 with the exception that the energy stored in the flywheel 37 may be varied depending on the number of seg-

ments 37a coupled to the torque tube 36. Upon reaching the preselected speed for the chosen mass, the clutch 35 is disengaged and the flywheel with its kinetic energy is coupled through clutch 38 to rotate the workpiece 46a. Through the pressure cylinder arrangement, the workpieces are joined together in frictional relationship and as the energy is expended from the flywheel, the surfaces of the rotating piece 46a and stationary piece 46b are rendered plastic or molten and joined through intermolecular penetration. Stoppage of the flywheel coincides with or substantially coincides with the completion of the weld. Thereupon, clutch 38 is disengaged and clutch 35 engaged to again store energy in the flywheel for the next weld while new workpieces are inserted in the chucks 40 and 45.

In the embodiment of Fig. 4, the arrangement is modified over the apparatus hereinabove described in that the torque tube, i.e. the flywheel shaft is offset from axial alignment as presented in Figs. 2 and 3. In connection with some welding operations, as where the workpiece is small as distinguished from a long workpiece requiring support afforded through the hollow torque tubes of Figs. 2 and 3, the arrangement of Fig. 4 may offer some advantage of expeditiousness. Also, this arrangement permits welds to be made in cases where the kinetic energy of a high speed flywheel is required while the surface sliding speed must be rather low, or in cases where the rotation speed must be lower than the speed of the flywheels, e.g. in the welding of thin-walled tubes.

As shown, motor 51, through motor pulley 52, drive belt 53 torque tube pulley 54 and first clutch 55, is arranged to drive torque tube 56. The flywheel 57 comprises four segments, two 57a of which are relatively smaller than the other two 57b, and any of which may be selectively coupled to the torque tube to supply a predetermined kinetic energy to effect a weld in workpieces secured in the rotating and non-rotating chucks 62 and 66, respectively. Bearing supports 68 for the torque tube 56 are suitably arranged to support the flywheel 57. The kinetic energy from flywheel 57 is transmitted from pulley 58 on torque tube 56 through belt 59 to a pulley 60 secured to and arranged to drive the hollow rotary shaft 69. The shaft 69 carries spindle 61 and rotating chuck 62 in which one of the workpieces 67a is secured preparatory to welding. The arrangement of pressure cylinders 63, piston rods 64 and the back-up plate 65 and non-rotating chuck is similar in function to the corresponding configuration described in Figs. 2 and 3 functioning to press the workpieces 67b held by the non-rotating chuck 66 against workpiece 67a in the direction of the arrow. A second clutch (not shown) is interposed either on the torque tube 56 or on the drive shaft 69.

In the operation of the arrangement of Figure 4, upon insertion of the workpieces in the chucks 62 and 66, the flywheel is brought up to suitable rotating speed until the predetermined kinetic energy is stored and thereafter clutch 55 is disconnected. The second clutch is engaged and the pressure cylinders are then actuated to force workpiece 67b against 67a. During the interval required to exhaust the kinetic energy from flywheel 57, sufficient heat has been generated at the interface of pieces 67a and 67b to render it plastic or molten. The pressure provided between the workpieces by means of cylinders 63 through rods 64 affords the necessary force to weld the heated workpieces.

While in the description hereinabove, pressure of the workpieces together has been provided by a cylinder and piston arrangement, it will be apparent that any means suitable for exertion of adequate pressure for the workpieces to be welded may be used in lieu thereof, due consideration being given to the size of the workpieces to be welded. For example, springs, levers or jack screws may be employed to exert the required pressure.

The following example illustrates the utilization of the invention:

Steel workpieces were welded using approximately 2,800 ft—lbs of energy stored in the rotating elements of the welder whose inertia is about 0.035 slug—ft^2. A 7/16 in. diameter, 1020 steel stud was rotated at an angular speed of 3840 rpm which produced a peripheral speed of 7.3 fps. A 35,400 psi contact pressure was applied at the instant the workpieces were brought into frictional engagement for welding. The weld was completed (rotation of the flywheel stopped) in 0.7 sec. The rotating mass of the flywheel under the stated conditions supplied energy at a rate of about 50 hp per sq in. to the pieces being welded during 0.7 sec. The heat affected zone was confined to a flat, thin band about 1/32 in. wide which proves that the energy was efficiently used. The material immediately adjacent to the weld was unaffected by the welding process.

While the selection of a properly dimensioned flywheel and its rotation at suitable speeds to give suitable welds for a given pair of workpieces may be obtained by trial and error, i.e. by the resulting effect on the workpieces welded as, for example, by the amount of upset material, a more appropriate determination may be obtained through calculation. Figures of the accompanying drawing and the formulae which follow are provided as a more specific disclosure to aid one skilled in the art in the manner and process of utilizing the inventive contribution.

Figure 5 is a diagram showing a workpiece 90 and an elementary area on the friction plane 91 over which heat is developed at the butt end of a solid bar. A simple analytical

expression for the friction force acting on the incremental area dA at the weld interface, $dA = 2\pi\rho\, d\rho$, is given by the expression:

$$dF = 2pf\pi\rho\, d\rho \qquad (1)$$

wherein dF is the incremental frictional force; p is the unit pressure; f the coefficient of friction; π is 3.1416; ρ is any given radius in the cross-section of the workpiece; and $d\rho$ the incremental change in radius.

The incremental power dP released during welding over this area is given by the expression:

$$dP = 4\pi^2 pfn\rho^2\, d\rho \qquad (2)$$

wherein n is the angular speed in rpm.

Fig. 6 is a graph of the effective coefficient of friction as a function of rotational speed and contact pressure for 3/8 in. diameter bars of AISI 4140 steel welded to type 304 stainless steel. The curves of effective coefficient of friction as a function of contact pressure or rotational speed are for surfaces heated to the steady state condition. The abscissa A shows how variations in contact pressure affect the coefficient of friction, and the abscissa B shows how the coefficient of friction decreases as the rotational speed increases. In Fig. 6, the coefficient of friction f of these workpieces was measured at various rotational speeds and pressures and found not to be constant.

Although the coefficient of friction may be averaged for some rough calculations, it is a variable which is dependent upon surface sliding speed, pressure, temperature, etc. However, for steady state conditions, the coefficient of friction f is mostly affected by speed of rotation and can be written as

$$f = k/(2\pi nR)^x \qquad (3)$$

wherein k is a constant whose value is determined by experiment and x is some number greater than zero. If a solid bar is to be welded, R is the radius of the workpiece. If a tube or pipe or other geometry is to be welded, then R represents the equivalent radius of the workpiece at the friction plane. For the present calculations, x is considered between 0 and 2 as observed by experimentally measuring the coefficient of friction and plotting curves similar to Fig. 6 and observing their shape.

By replacing f with $k/(2\pi nR)^x$ in Eq. 2 and integrating over the cross-section, the following representative expressions are obtained for the power consumed during welding. These illustrate how the power consumed during welding depends upon the character of the coefficient of friction. These expressions are identified as Case I, Case II, and Case III for assumed values of x of 2, 1, and 0.

$$\text{Case I} \quad \rho = pkR/n \ \text{if} \ x=2, \ \text{i.e.,} \ f = k/(2\pi nR)^2 \qquad (4)$$

$$\text{Case II} \quad \rho = \pi pkR^2 \ \text{if} \ x=1, \ \text{i.e.} \ f = k/(2\pi nR) \qquad (5)$$

$$\text{Case III} \quad \rho = \frac{4}{3}\pi^2 pkR^3 n \ \text{if} \ x=0, \ \text{i.e.,} \ f = k \qquad (6)$$

These expressions illustrate the necessity of countering the slope of the coefficient of friction curve with the slope of the energy storage curve of a flywheel in such a way as to attune the two systems together to effect complete utilization of frictional energy to provide an optimum weld substantially coincidental with exhaustion of kinetic energy from the flywheel.

The flywheel equation is

$$K.E. = 2\pi^2 I n^2 \qquad (7)$$

where, K.E. is the kinetic energy stored in the flywheel, ft—lbs; I is the inertia of the flywheel, slug—ft^2; and n is the angular speed of the flywheel, rps.

To illustrate, it will be assumed that a simple, disc-type flywheel is used having for its inertia

$$I = \frac{1}{2}\,\frac{w}{g}\,r^2 \qquad (8)$$

where, w is the weight of the flywheel, lbs; g is the gravitational constant, 32.2 ft/sec^2; and r is the radius of the flywheel, ft.

It should be noted that the flywheel equation (8) states that the power stored in the flywheel is proportional to the square of its speed. Since the coefficient of friction in-

creases faster than the speed of rotation decreases as shown in Fig. 6, a combination of circumstances takes place to cause a rapid discharge of energy. This results in the flywheel being rapidly decelerated and stopped without the need for a separate braking system.

The total energy required to make the weld equals the frictional heating power multiplied by the welding time. This is set equal to the energy stored in the flywheel. For Cases I, II, and III, the equations describing the welding time t can be written as:

$$\text{Case I} \ \left(\frac{pkR}{n}\right)t = \pi^2\,\frac{w}{g}\,n^2 r^2$$

$$\text{or} \ t = \pi^2\,\frac{w}{g}\cdot\frac{n^3 r^2}{p\,k\,R} \qquad (9)$$

$$\text{Case II} \ (\pi pkR^2)\, t = \pi^2\,\frac{w}{g}\,n^2 r^2$$

$$\text{or} \ t = \pi\,\frac{w}{g}\,\frac{n^2 r^2}{p\,k\,R^2} \qquad (10)$$

$$\text{Case III } (-\frac{4}{3}\pi^2 \, pkR^3 n) \quad t = \pi^2 -n^2 \, r^2 \frac{w}{g}$$

$$\text{or } t = \frac{3}{4} \frac{w}{g} \frac{n \, r^2}{pkR^3} \qquad (11)$$

where t is the welding time.

To further illustrate the advantages of the

Speed, $n =$ 60 rps
Welding time, $t =$ 10 secs
Contact pressure, $p_1 =$ 5,000 psi, during heating (10 secs)
       $p_2 =$ 20,000 psi, during forging (after rotation stops)

During the heating phase, 6,600 ft—lbs of energy were converted to heat at the weld plane. This is equivalent to an average energy rate of 660 ft—lb/sec; therefore, about 11 hp per sq in. is required to weld the material during the 10 second interval.

On the other hand, when the flywheel of the invention is used, it is only required to use 2685 ft—lbs of energy which is less than 1/2 the regular amount. The weld is com-

Initial speed, $n = 60$ rps
Inertia of flywheel, $I = 0.038$ slug—ft^2
Measured welding time, $t = 2.0$ secs
contact pressure, $p = 10,000$ psi during heating and forging

According to the manner in which the coefficient of friction behaves as a function of rotational speed as shown in Fig. 6, Case I seems to apply most closely for these materials. Consequently, it is possible to estimate the welding time, t, for this situation beforehand provided k is known. The value for k can be calculated from Eq. 3 and Fig. 6 where:

$$k = f \, (2\pi nR)^2 = 5.5$$

and wherein $f = 0.16$; $n = 60$ rps; and $R = 1/64$ ft.

Substituting this information into the Eq. 9 for Case 1 and using the proper units, the time t, to make the weld is obtained.

$$t = \pi^2 \frac{w}{g} . \frac{n^3 \, r^2}{p \, k \, R} = 1.4 \text{ secs}$$

where: $w = 40$ lb, the equivalent weight of the flywheel; $n = 60$ rps, the initial speed of the flywheel; $r = 1/4$ ft, the equivalent radius of the flywheel; $R = 1/64$ ft, radius of the workpiece; $p = 10,000$ psi; and $k = 5.5$.

The 2.0 sec. welding time checks closely with the 1.4 second estimated value and shows that the conditions occur as described. During the 2.0 seconds, energy is developed at the weld plane at a rate of 27 hp per sq in. as compared to 11 hp per sq in. by the conventional method. The welds obtained by the flywheel method are equal or better in all respects to the best obtainably by conventional friction welding methods. Because the heat is produced rapidly and is localized, it

invention a series of experiments were carried out in which friction welds made using a conventional drive and braking friction welding arrangement and compared to those made by the flywheel method. Butt welds were made between 3/8 in. diameter bars of AISI 4140 alloy steel and SAE 304 stainless steel. For the conventional case, the following parameters were required:

pleted in only 2.0 seconds. Less energy is required because the cycle time is much shorter; and there is less opportunity for the heat, which is developed by friction, to be carried away by conduction. The 2685 ft—lbs of energy was stored in an inertia mass of 0.038 slug—ft^2. For the purpose of calculation, this is equivalent to a simple 6 in. diameter disc-type flywheel weighing about 40 lbs.

is possible to join materials of different melting points and physical properties such as aluminum to steel, a result heretofore unobtainable with conventional friction welding apparatus.

The term "flywheel" as used herein contemplates any mass rotating about an axis such that it effectively has a mass moment of inertion, including discs, spoked wheels, flyballs, etc.

It will be apparent to those skilled in the art that various modifications may be made in the invention without departing from the scope of the invention. Accordingly, the invention is not to be limited by various specific details set forth primarily to provide a full, clear and exact description except insofar as necessitated by the appended claims.

WHAT WE CLAIM IS:—

1. A friction welding machine comprising a pair of gripping means for gripping workpieces, a rotary device for effecting relative rotation of the gripping means, pressure means for urging the gripping means relatively towards each other so as to press the workpieces together, a flywheel, a power driven means, a first clutch disengageably coupling the power driven means to the flywheel, a second clutch disengageably coupling the flywheel to the rotary device, the arrangement being such that with the second clutch disengaged sufficient kinetic energy can be intro-

duced through the first clutch into said flywheel to effect the weld whereupon the second clutch can be engaged and the pressure means operated to press the workpieces together to 5 effect the weld, the second clutch can be then disengaged and the flywheel again driven up to required speed through the first clutch for another weld, no braking means being provided for slowing the rotary movement of the 10 flywheel.

2. A friction welding machine as claimed in claim 1, wherein the pair of gripping means are coaxial one of which can be connected by the second clutch with said flywheel, said 15 flywheel and clutches being coaxial with said gripping means, and means being provided for connecting the input part of the first clutch with a motor constituting said power driven means.

3. A friction welding machine as claimed 20 in claim 1 wherein the flywheel comprises selectively utilisable segments.

4. A friction welding machine as claimed in claim 1 substantially as described, with reference to the accompanying drawings. 25

For the Applicants:
MATTHEWS, HADDAN & CO.,
Chartered Patent Agents,
31/32 Bedford Street,
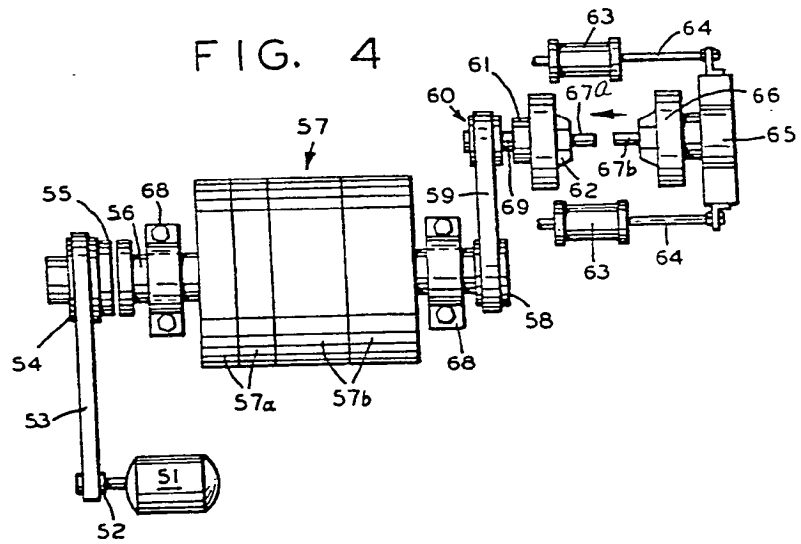Strand, London, W.C.2.

FIG.
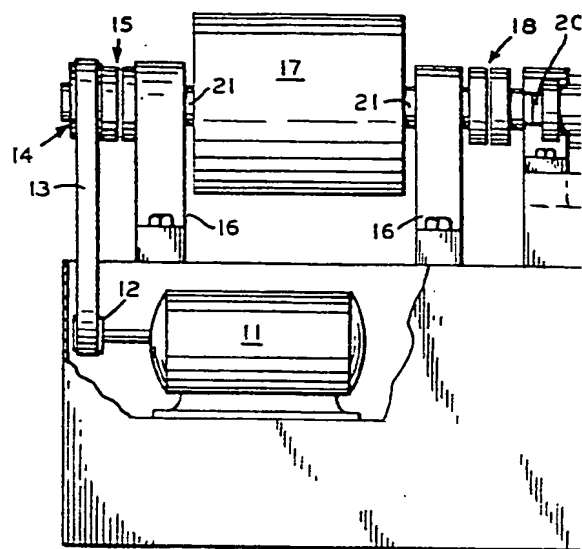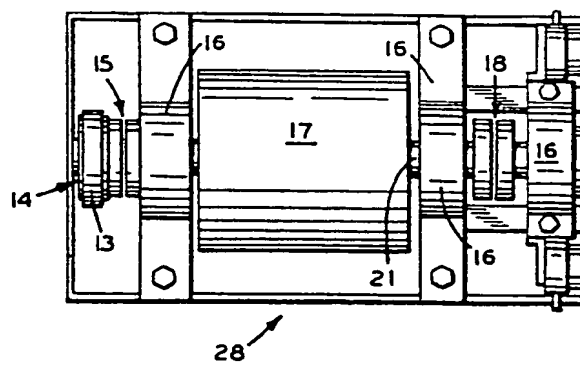
FIG. 2

BEST AVAILABLE COPY

FIG. 1

FIG. 2

FIG. 1
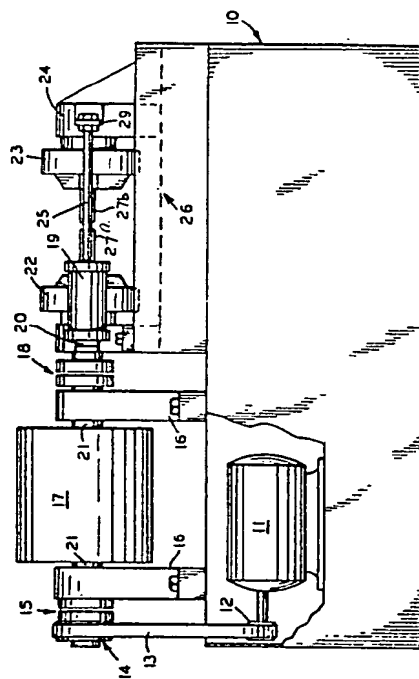
FIG. 2

FIG. 3

FIG. 4

B·

A

FIG. 5

FIG. 6

FIG. 5

FIG. 6

FIG. 3

FIG. 4